

(Anomalous) X-ray Pulsars

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We review the observational properties of the class of young neutron stars known as “anomalous X-ray pulsars,” emphasizing the tremendous progress that has been made in recent years, and explain why these objects, like the “soft gamma repeaters,” are today thought to be young, isolated, ultrahigh magnetic field neutron stars, or “magnetars.”

1. INTRODUCTION

Prior to the commissioning of *BeppoSAX* and the *Rossi X-ray Timing Observatory* in 1996, the so-called “Anomalous” X-ray Pulsars (AXPs) were considered very mysterious sources, because the energy source for their bright X-ray emission was unknown. At the time, there were only 3 known members of this class. They were distinguished by having periods in the narrow range 6–9 s, showing approximately steady spin-down, and having softer spectra in general than those seen in accreting X-ray pulsars. All were known to lie within 1° of the Galactic Plane, and interestingly, one source, 1E 2259+586, was known to reside in the supernova remnant CTB 109. AXPs as a class were identified as having modest X-ray luminosities, in the range $L_x \sim 10^{34} - 10^{35}$ erg s⁻¹. The leading model to explain the AXPs was that they were accreting neutron stars, though with properties very different from the bulk of established accreting X-ray pulsars, including the absence of any evidence of a companion (van Paradijs et al., 1995; Mereghetti & Stella, 1995).

The situation post-*BeppoSAX* and especially in the latter years of *RXTE* is very different and much clearer. The basic phenomenology of the sources is now well mapped out. Here, we systematically review the most important properties of this class of objects, which now includes 5 and possibly 8 sources (see Tables 1 and 2),

and summarize why today, accretion models are strongly disfavored. Rather, the magnetar model, in which AXPs are isolated young neutron stars powered by a decaying ultrahigh magnetic field, provides the most compelling explanation for the unusual AXP source properties, as it does for an equally as exotic class, the soft gamma repeaters (SGRs). AXPs have also been reviewed recently by Mereghetti et al. (2002), and magnetars in general have been reviewed recently by Kaspi (2003a,b).

2. TIMING PROPERTIES OF AXPS

Since their discovery, AXPs have been known to be spinning down. Unlike most known accreting X-ray pulsars, no evidence was seen, in nearly two decades of timing, for any extended spin-up. However, some deviations from simple spin-down were observed. AXP 1E2259+586 showed a handful of possible very short lived spin-up events (e.g. Baykal & Swank, 1996) as did 1E 1048–5937 (e.g. Oosterbroek et al., 1998). These were noted by various authors and were suggested to be due to accretion torque variations (e.g. Baykal & Swank, 1996), glitches (Heyl & Hernquist, 1999), and magnetar radiative precession (Melatos, 1997). However, with sparse observations consisting of a frequency measurement every few years and rarely more often, determining the origin of the apparent deviations from simple spin-down could not be done.

In order to address this problem, a program of

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Table 1: Spin parameters for AXPs.

Source	Distance [†] (kpc)	SNR	P (s)	\dot{P} ($\times 10^{-11}$)	B_{dp} ($\times 10^{14}$ G)	\dot{E}_s ($\times 10^{32}$ erg s $^{-1}$)	τ_c (kyr)	Ref.
4U 0142+61	$\gtrsim 1.0$ or $\gtrsim 2.7$	—	8.69	0.196	1.3	1.2	7.0	1
1E 1048–5937	$\gtrsim 2.7$	—	6.45	~ 3.81	~ 5.0	~ 55	~ 2.7	2
RXS 1708–4009	~ 8	—	11.00	1.86	4.6	5.4	9.4	3
1E 1841–045	5.7–8.5	Kes 73	11.77	4.16	7.1	9.9	4.5	4
1E 2259+586	3	CTB 109	6.98	0.0483	0.59	0.55	230	5
AX J1845.0–0258*	~ 8	Kes 75	6.97	—	—	—	—	6
CXOU J0110043.1–721134*	57	—	8.02	—	—	—	—	7
XTE J1810–197*	~ 10	—	5.54	1.15	2.6	26	7.6	8

(*) not confirmed; (†) see Özel, Psaltis & Kaspi 2001 for a discussion on distance estimates for the confirmed AXPs; References: (1) Gavriil & Kaspi 2002; (2) Kaspi et al. 2001; (3) Kaspi & Gavriil 2003; (4) Gotthelf et al. 2002; (5) Woods et al. 2003; (6) Torii et al. 1998; (7) Lamb et al. 2003; (8) Ibrahim et al. 2003.

Table 2: Spectral parameters for AXPs.

Source	n_H ($\times 10^{22}$ cm $^{-2}$)	Γ	kT (keV)	L_x (erg s $^{-1}$)	f_{pl} (%) [†]	Ref.
4U 0142+61	0.88	3.3	0.42	3.3×10^{34}	~ 88	1
1E 1048–5937	1.0	2.9	0.63	3.4×10^{34}	~ 80	2
RXS 1708–4009	1.49	3.11	0.45	6.8×10^{35}	~ 73	3
1E 1841–045	2.0	2.26	—	2.3×10^{35}	100	3
1E 2259+586	0.93	3.6	0.41	1×10^{35}	~ 50	4
AX J1845.0–0258*	9.0	4.6	—	7.4×10^{34}	100	5
CXOU J0110043.1–721134*	0.14	—	0.41	1.5×10^{35}	0	6
XTE J1810–197*	1.05	3.75	0.668	1.6×10^{36}	~ 70	7

(*) not confirmed; (†) contribution of the power-law component to the total flux, see Perna et al. 2001 for further discussion; References: (1) Juett et al. 2002; (2) Tiengo et al. 2002; (3) Mereghetti et al. 2002; (4) Patel et al 2001; (5) Torii et al. 1998; (6) Lamb et al. 2003; (7) Ibrahim et al. 2003.

regular monitoring of the 5 confirmed AXPs by *RXTE* was initiated in 1998. The goal was to accomplish phase-coherent timing, in which every rotation of the neutron star is counted on time scales of months to years. Phase-coherent timing is done regularly for radio pulsars, and is effective with any periodic source in which the periodicity is very stable, or at least changes relatively slowly. This turned out to apply nicely to the AXPs (Kaspi et al., 1999). For example, the RMS phase residual for 1E 2259+586 in ~ 5 yr of timing (pre-June 2002) is under 2% of the pulse period, following the removal of a model having only three free parameters (Gavril & Kaspi, 2002, hereafter GK02). Phase-coherent timing on long time scales has now been accomplished for AXPs RXS J1708–4009 (Kaspi et al., 1999), 4U 0142+61 (GK02) and 1E 1841–045 (Gotthelf et al., 2002) and indicates these sources are capable of great rotational stability. This stability argues against an accretion origin of the X-rays, since most accreting sources show much higher levels of torque noise (but see Baykal et al., 2001). The stability is comparable in some cases (particularly 4U 0142+61 and 1E 2259+586) to that seen in young radio pulsars. Together with the much noisier timing properties of SGRs (e.g. Woods et al., 1999), this provides support for a continuum of timing noise properties in the radio pulsar, AXP and SGR populations, in line with the magnetar model.

However, one AXP, 1E 1048–5937, is a much noisier rotator than the others, so much so that phase-coherent timing cannot be accomplished over more than a few months at a time (Kaspi et al., 2001). More detailed observations of the source reveal that its spin-down rate can change on time scales of weeks, and by large factors (see Fig. 1; Gavril & Kaspi, in preparation). This behavior is reminiscent of that seen in SGRs 1806–20 and 1900+14 (Woods et al., 2002).

Thus, deviations from simple spin-down in AXPs appears to come in three flavours: (i) glitches and subsequent recovery; (ii) low-level stochastic variations having a “red” spectrum, similar to the “timing noise” seen in radio pulsars; and (iii) large, short-time-scale variations which preclude phase connection. The origin of

the latter two in particular is unknown. The low-level variations in radio pulsars may be related to crustal superfluid effects such as “mini-glitches”, or may, in some cases, result from long-term recoveries from glitches that preceded the commencement of the observations. Arras et al. (2003) have recently suggested that the larger-scale torque variations arise from angular momentum transfer from a superfluid core. Such a core, they argue, also results in a reduction in the interior temperature that could make the crust more brittle, hence result in greater burst activity as seen in the SGRs (and possibly 1E 1048–5937; see §6).

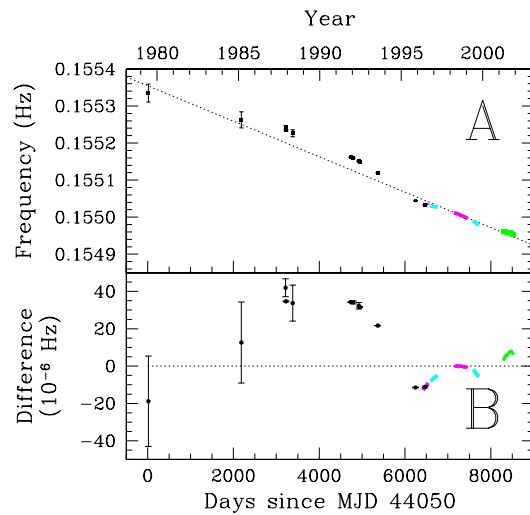


Figure 1. Top: Long-term frequency history of 1E 1048–5937 (after Kaspi et al. 2001). The heavy lines represent intervals over which phase-coherent timing was possible. Bottom: Same data but with the linear trend removed.

2.1. Glitches

Because phase-coherent timing counts every rotation, it determines spin parameters with high precision. This permits sensitivity to glitches having fractional amplitudes as low as $\sim 10^{-7}$. The first AXP glitch was detected in RXS

J1708–4009 (Kaspi et al., 2000), and had fractional amplitude 6×10^{-7} , and an increase in the magnitude of the spin-down rate of $\sim 1\%$. These glitch properties are similar to those seen in Vela-like radio pulsars. Interestingly, this source glitched again ~ 1.5 yr later (Kaspi & Gavril, 2003; Dall’Osso et al., 2003). However, the second glitch was much larger, with fractional frequency change 4×10^{-6} , and a significant post-glitch recovery in which nearly all of the glitch relaxed on a time scale of ~ 50 days. The frequency history of this source is shown in Figure 2. Neither glitch was accompanied by any obvious radiative changes.

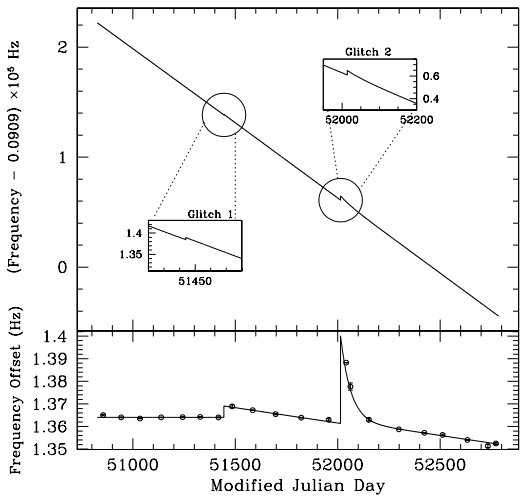


Figure 2. Frequency history of RXS J1708–4009 showing the two very different glitches. The top plot shows the overall frequency evolution, while the bottom plot shows the same but with the long-term spin-down trend removed, as well as measured frequencies. The best-fit model is based on a phase-coherent analysis (after Kaspi & Gavril 2003).

The second discovered AXP glitch was in 1E 2259+586 (Kaspi et al., 2003; Woods et al., 2003). Unlike the RXS J1708–4009 glitches, this one occurred simultaneously with (or possibly a

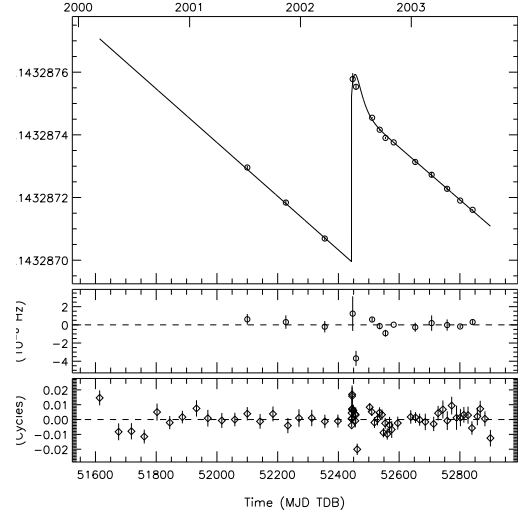


Figure 3. Frequency history of 1E 2259+586 around the time of its 2002 outburst based on a phase-coherent analysis. The top plot shows the frequency evolution around the glitch, along with measured frequencies. The middle panel shows frequency residuals, while the bottom shows phase residuals (after Woods et al. 2003).

few hours before – see Woods et al. 2003) a major outburst in which over 80 X-ray bursts were detected in just a few hours, in addition to sudden order-of-magnitude increases in the pulsed and unpulsed flux, significant pulse profile changes, and an infrared enhancement (all discussed below). This represents the first neutron-star glitch ever observed to be accompanied by significant radiative changes, and clearly indicates a major event that simultaneously affected both the internal and external structure of the star. Roughly 20% of the glitch recovered on a time scale of weeks, and in doing so resulted in the stellar spin-down being a factor of > 2 greater than its pre-outburst value (Fig. 3). This is unprecedented in radio pulsars, and suggests that just following the glitch, the neutron star superfluid was actually spinning *slower* than the crust, with the observed subsequent enhanced spin-down a result of angular momentum transfer from the crust back to the superfluid (Woods et al. 2003). Additionally,

there was evidence that the glitch may have been resolved in time, on a time scale of ~ 2 weeks.

Glitches are definitely expected in the magnetar model (e.g. Thompson & Duncan, 1996). As pointed out by Kaspi et al. (2000), at least in principle, an accreting source can undergo a spin-up glitch since the latter results from an internal angular momentum transfer from superfluid to crust regardless of the nature of the external spin-down torque. However, one would not expect simultaneous bursts in an accretion scenario, as one might in the magnetar model.

The observed AXP glitches provide a very plausible explanation for the historically observed spin-down deviations at least in 1E 2259+586 (Baykal & Swank 1996). The picture is still not clear for 1E 1048–5937, however.

3. AXP X-RAY PULSE PROFILES AND PULSED FRACTIONS

AXP pulse profiles are, like those of the SGRs, broad, with large ($\gtrsim 80\%$) duty cycles, and generally significant harmonic content (e.g. GK02). The profiles show energy dependences that vary from source to source. A possible trend of greater energy dependence for profiles with higher harmonic content was identified by GK02, who also showed that in general, AXP pulse profiles are very stable.

However, in 2002 June, simultaneously with the detection of the glitch and X-ray bursts, the pulse profile of 1E 2259+586 underwent significant changes, on time scales from hours to days (Kaspi et al. 2003; Woods et al. 2003). The profile had relaxed back to its pre-outburst morphology by ~ 2 weeks following the outburst. Iwasawa et al. (1992) observed an apparent change in the X-ray pulse profile of 1E 2259+586, in which the relative amplitude of the two peaks in the profile changed between observations made in 1989 and 1990. This can be explained as being due to an outburst having occurred just before the 1990 observation (see §5).

AXP pulsed fractions vary from source to source, with the highest being ~ 0.8 for 1E 1048–5937 and the lowest being ~ 0.1 for 4U 0142+61. Some, but not all, are energy depen-

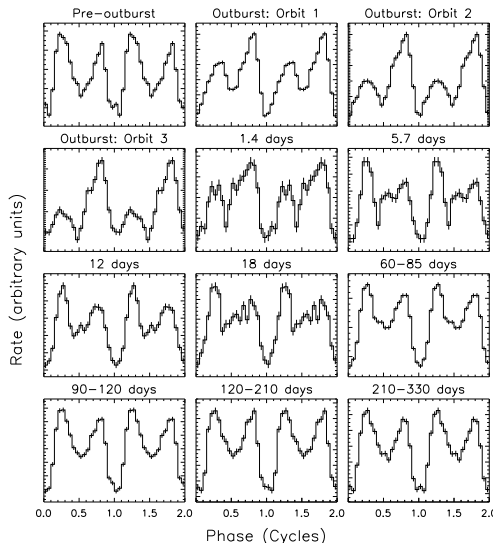


Figure 4. Pulse profile changes in 1E 2259+586 seen around the time of the 2002 June outburst (after Woods et al. 2003).

dent, and those which vary differently with energy. For a summary of AXP pulsed fractions and their energy dependences, see Özel et al. (2001). It is not clear whether the pulsed fractions are time variable in general. However, the pulsed fraction of 1E 2259+586 clearly changed at the time of its 2002 outburst: immediately post-outburst, the pulsed fraction decreased from its quiescent level of ~ 0.23 to ~ 0.15 , however it recovered fully after 3 days (Woods et al. 2003).

4. X-RAY SPECTRA

X-ray spectra of AXPs generally require two components. These are usually taken to be a thermal blackbody component with a power-law tail. The measured spectral parameters of the known AXPs are given in Table 2. The spectra as a class are softer than those of the SGRs in quiescence. The softest source in that class is SGR 0525–66; its spectral parameters are actually softer than those of 1E 1048–5937, which, among other things, prompted Kulkarni et al. (2003) and Kaspi et al. (2001) to suggest these sources may be transition objects between the two

classes.

In the context of the magnetar model, the spectra can be understood as follows. The thermal component is emerging from the stellar surface, a result of heating of the interior by active magnetic field decay (Thompson & Duncan, 1995; Thompson & Duncan, 1996). The thermal spectrum is thought to deviate significantly from that of a blackbody, because of the effects of the stellar atmosphere, as well as the large magnetic field, which results in different opacities for different photon polarizations, as well as on QED vacuum polarization (Ho & Lai, 2001; Özel, 2001; Zane et al., 2001; Ho & Lai, 2003; Özel, 2003). The thermal spectrum is hardened relative to a blackbody of the same temperature due to the non-grey atmosphere, although vacuum polarization counteracts this slightly. As observers fit the thermal component with a blackbody, some portion of the non-thermal component may result from the atmospheric distortion. However, this portion is probably small. A more promising origin of the non-thermal emission is external resonant Compton scattering of thermal seed photons by magnetospheric currents (Thompson et al., 2002).

The X-ray spectra were, pre-*Chandra* and *XMM-Newton*, hoped to hold direct evidence for the high magnetic field via features such as electron cyclotron lines (e.g. Ho & Lai, 2001; Zane et al., 2001; Özel, 2003; Ho & Lai, 2003). Of course an electron cyclotron line in a $\sim 10^{15}$ G field might look similar to a proton cyclotron line in a $\sim 10^{12}$ G field. In any case, no such lines have been seen in spite of some high spectral, and in some cases, temporal resolution observations (Patel et al., 2001; Juett et al., 2002; Tiengo et al., 2002; Woods et al., 2003).

5. AXP X-RAY FLUX VARIABILITY

Strong flux variability pre-*BeppoSax* and *RXTE* was reported for 1E 2259+586 and 1E 1048–5937 (Baykal & Swank 1996; Oosterbroek et al. 1998). Flux variations of a factor of 5–10 were reported, albeit from different instruments, having different spectral responses, with some imaging and some not. However Iwa-

sawa et al. (1992) reported a brightening of a factor of ~ 2 in a 1990 *GINGA* observation of 1E 2259+586 compared with an observation in 1989. They noted that the 1990 pulse profile was also significantly different than that observed previously, with different relative peak amplitudes, and different peak shapes. Furthermore, the measured 1990 spin period was fractionally shorter by $\sim 3 \times 10^{-6}$ compared with what the previous spin-down rate would have predicted.

In ~ 5 yr of monitoring using the PCA on *RXTE*, GK02 found no evidence for such flux variations in any AXP. This was consistent with what was found by Tiengo et al. (2002) in a comparison of past observations of 1E 1048–5937 with recent *XMM-Newton* data. The overall recent lack of variability in AXPs thus appeared discrepant with the historical record.

The 2002 June outburst of 1E 2259+586 appears to have solved this conundrum, at least for this source. Simultaneous with the bursting were increases in the and persistent fluxes by a factor of > 10 (Kaspi et al. 2003; Woods et al. 2003), which mostly decayed on a time scale of days, but which has left an X-ray afterglow in which the pulsed flux is still a factor of ~ 2 greater than the pre-outburst value a year since the outburst (Fig. 5). The total energy in excess pulsed and persistent emission during the short-decay-time-scale enhancement was 3×10^{39} erg (2–10 keV), while that in the extended afterglow is much more, 2×10^{41} erg (Woods et al. 2003).

The rapidly decaying flux enhancement seen in 1E 2259+586 could be due to a transient surface hot spot. During the rapid initial flux decay, the blackbody radius was smaller than at all other times, the temperature was higher, and the pulse profile was clearly different, supporting this picture. Alternatively, it could have been magnetospheric, as a large current density will be excited in the magnetosphere above regions of strong crustal shear. The short-lived afterglows detected after intermediate SGR bursts have a simple explanation as the cooling of a pair-rich surface layer heated by a high-energy flare (Ibrahim et al., 2001). However, no such flare was seen for 1E 2259+586. This is problematic also for explaining the long-time-scale af-

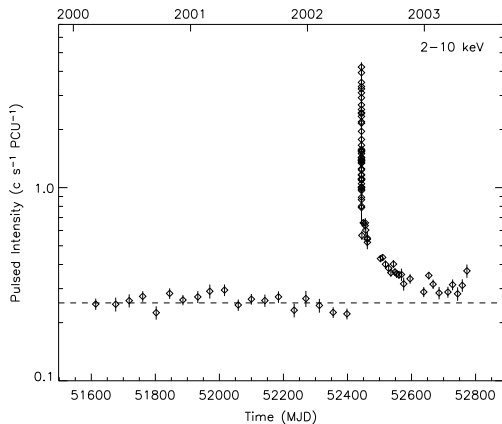


Figure 5. The pulsed flux history of 1E 2259+586 (2–10 keV) around the time of the outburst, indicated by the sharp spike (after Woods et al. 2003).

terglow. In SGRs, bulk heating of the crust can power an excess heat flux from its surface for a year or more, and has been proposed as the explanation for the quasi-power-law flux decay seen in SGR 1900+14 (Lyubarsky et al., 2002) and SGR 1627–41 (Kouveliotou et al., 2003). In each case, an initial deposition of 10^{44} ergs was assumed, consistent with the detection of an initial giant soft gamma-ray flare; this was unseen for 1E 2259+586. For a more detailed discussion of the possible origins of the enhanced emission, see Woods et al. (2003).

We note that the combination of the observed flux enhancement, glitch and pulse profile change in 1E 2259+586 observed by Iwasawa et al. (1992) using *GINGA* are consistent with an outburst similar to that observed in 2002 June having occurred days/weeks prior to their 1990 observation (see §3). This offers an estimate of a crude burst rate of two every ~ 20 yr.

This observed variability associated with outbursts also makes the two transient AXP candidates (see Table 1), AX J1845–0258 (Vasisht & Gotthelf, 1997), and XTE J1810–197 (Ibrahim et al., 2003) easier to understand. These two objects have both shown factor of > 10 increases in their fluxes. For XTE J1810–197, the

flux decreased slowly after its appearance, in concert with its spin-down rate, not unlike the behavior seen in 1E 2259+586 post-outburst (Ibrahim et al. 2003; Woods et al. 2003). Such transient AXPs suggest a large population of quiescent AXPs exists in the Galaxy.

6. X-RAY BURSTS

The first discovery of bursts from AXPs came from the *RXTE*/PCA monitoring observations of 1E 1048–5937. Two faint bursts, separated by ~ 2 weeks, were detected in ~ 425 ks of exposure over ~ 5 yr (Gavril et al., 2002). These bursts very much resemble SGR bursts. Specifically, their fast rise times, short durations, hard spectra relative to the quiescent emission, fluence and probably clustering, are all SGR burst hallmarks. The origin of the bursts could not unambiguously be proven to be the AXP, given the large PCA field-of-view, and the absence of any other radiative or spin change in the source. Intriguingly, the first burst’s spectrum was not well fit by a continuum model, showing evidence for a strong emission line at ~ 14 keV.

Not long after the reporting of the above two bursts, a major outburst consisting of over 80 bursts was detected from the direction of 1E 2259+586 fortuitously during a regular *RXTE*/PCA monitoring observation in 2002 June (Kaspi et al. 2003). These bursts were very similar to those of SGRs (Gavril et al., 2003). Specifically, like the SGRs, the AXP burst durations follow a log-normal distribution which peaks at 99 ms, the differential burst fluence distribution is well described by a power law of index -1.7 , the burst fluences are positively correlated with the burst durations, the distribution of waiting times is well described by a log-normal distribution of mean 47 s, and the bursts are generally asymmetric with faster rise than fall times.

However, there were some notable differences between the AXP and SGR bursts that may be clues to the physical differences between the two source classes (Gavril et al. 2003). Specifically, the AXP bursts exhibit a wider range of durations and, unlike SGR bursts, occur preferentially near pulse maxima; the correlation be-

tween burst fluence and duration seen for SGRs is flatter than for SGRs; the AXP bursts are on average less energetic than are SGR bursts; and the more energetic AXP bursts have the hardest spectra – the opposite of what is seen for SGRs (Gavril et al. 2003). Furthermore, in stark contrast to SGRs, the energy detected in bursts (6×10^{37} erg, 2–60 keV) was much smaller than that in the post-outburst persistent flux enhancement (2×10^{41} erg, 2–10 keV). This could indicate bursting activity that was missed by our observations and the gamma-ray monitors, although the latter would have easily detected SGR-like bursts having the missing energy (Woods et al. 2003). This “quiet” outburst strongly suggests there are many more such objects in the Galaxy than was previously thought, as is also indicated by the transient AXP candidates (see §5).

Overall, the properties of the outburst in 1E 2259+586 argue that the star suffered a major event that was extended in time and had two components, one tightly localized on the surface of the star (i.e. a fracture or a series of fractures) and the second more broadly distributed (possibly involving a smoother plastic change). The glitch points toward a disturbance within the superfluid interior while the extended flux enhancement and pulse profile change suggest an excitation of magnetospheric currents and crustal heating. The very rich data set provided by this outburst should be very useful in constraining physical properties of the affected neutron star.

7. OPTICAL/IR OBSERVATIONS AND VARIABILITY

Of the five confirmed AXPs, four now have secure or possible optical/IR counterparts. The first optical/IR detection of an AXP was made of 4U 0142+61, by Hulleman et al. (2000). They argued that the source, which had $R \simeq 25$ mag, was too dim to be from an accretion disk. This was confirmed by Kern & Martin (2002) who showed that this source is pulsing with the X-ray period and a 27% pulsed fraction, much too high to be reprocessed light. Hulleman et al. (2001) discovered a possible near-IR ($K_s = 21.7$ mag) counterpart to 1E 2259+586. This was con-

firmed by Kaspi et al. (2003) who found the source to have brightened by a factor of ~ 3 three days after its 2002 outburst, but faded by a factor of ~ 2 1 week later. This source appears to have stayed brighter than pre-outburst, however, two months after the outburst (Israel et al., 2003b). Wang & Chakrabarty (2002) reported a likely near-IR counterpart to 1E 1048–5937 having $K = 19.4$ mag, and detected in multiple wavebands. Israel et al. (2002) reported significant IR variability in the source on a time scale of ~ 50 days. They speculated the variability might be related to bursting activity from this source (Gavril et al. 2002), in analogy with the variability seen in 1E 2259+586. Israel et al. (2003a) reported the detection of a possible IR counterpart to RXS J1708–4009.

These detections are interesting for two reasons. First, as noted above, in two cases variability is observed; for 1E 2259+586, it is likely that it is associated with its 2002 June outburst. Such variability may therefore prove to be an important observational model constraint, although currently its origin in the magnetar model is unclear. Most likely the optical/IR emission is a product (or, given the large X-ray to optical/IR luminosity ratios, $L_x/L_{\text{IR}} > 500$, a byproduct) of radiation processes in the outer magnetosphere, and therefore is sensitive to the changes in the current structure induced by magnetic reconfigurations. Continued monitoring for correlated optical/IR and torque variations seems warranted, especially as a way of testing the proposed “twisted magnetosphere” model of magnetars (Thompson, Lyutikov & Kulkarni 2002). Second, as pointed out by Israel et al. (2003a), the spectral energy distributions of the optical/IR and X-ray emission show that the former is much too bright to be the simple extrapolation of the blackbody component of the X-ray spectrum. However, it is fainter than the extrapolation of the X-ray power-law spectral component, so calling it an “excess” may be premature.

8. CONCLUSIONS AND OPEN QUESTIONS

Since the 1996 commissioning of *BeppoSAX* and *RXTE*, our overall picture of AXPs has changed dramatically. The number of likely AXPs has nearly tripled, and our understanding of these unusual sources' properties has improved tremendously. Perhaps the single most important discovery is that the apparent resemblance of AXPs with SGRs noted by Thompson & Duncan in 1995 is more than skin deep: with the discovery of bursts from AXPs, the two source classes are now united unambiguously. Our next challenge is to learn how to extract physically interesting information from AXP and SGR observations. In this sense, their study is still in its infancy, with observations ahead of theory.

This said, there are obvious possibilities for fruitful observational investigation of AXPs. First, it would be nice to have a direct measurement of the inferred high magnetic field. As no X-ray spectral features have been forthcoming, another avenue is needed. X-ray polarization observations are an excellent possibility, particularly for the brightest AXPs. The detection of such polarization, in addition to confirming the high magnetic field, would be the first demonstration of the birefringence of the vacuum, as predicted by QED. In the shorter term, glitches in AXPs may offer a practical method of constraining the structure and physics of these objects. The simultaneity of the 1E 2259+586 glitch with its outburst and associated radiative changes, we suspect, is telling us a lot about the stellar structure. Continued patient timing of these objects has the potential to reveal correlations between glitch properties like amplitude and relaxation time scales with radiative properties, which will help us understand properties of the highly magnetized crust and superfluid interior. Optical/IR observations also offer hope of constraining magnetar outer magnetosphere processes, although its origin is not yet clear. Finally, there is the open question of the radio pulsar/AXP connection. Recently, several radio pulsars having inferred magnetic fields *higher* than that of 1E 2259+586 have been discovered, yet with no

evidence for any AXP-like X-ray emission (e.g. Pivovarov et al., 2000; McLaughlin et al., 2003). This is puzzling. It may simply reflect the fact that the magnetic field measured by P and \dot{P} is approximate only, in which case the discovery of more such radio pulsars should eventually result in the identification of the “missing link.”

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